Recommended Fish Protection Procedures for Stream Crossings in Manitoba

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MANITOBA
DEPARTMENT OF NATURAL RESOURCES
Fisheries Branch

RECOMMENDED FISH PROTECTION PROCEDURES FOR STREAM CROSSINGS IN MANITOBA

F O R W A R D

Fishing and Manitoba roads - unlikely candidates for a feud. But the fact is, road and highway construction can be bad for fish and fish habitat. And of course, what's bad for fish is bad for the Sport and Commercial fisheries.

The advantages of a good road transportation system to the efficient development of our fisheries resource are obvious, but road construction practices at river and stream crossings can create serious problems for the Fisheries Manager.

Water flow constriction is the most common of these. Improperly constructed stream crossing structures can effectively block normal fish movements and migrations. The inevitable result is a depleted local fisheries resource.

The adverse effects of stream crossing structures can be reduced or eliminated with appropriate design alterations. The Fisheries Branch of the Department of Natural Resources has prepared the following recommendations as an aid to engineers and developers so that stream crossings can be constructed to minimize damage to fish and fish habitat.

These recommendations are based on an extensive review of what is currently known about stream crossing problems. Therefore, they are quite general and not always applicable to specific situations. So, road builders are urged to contact the Regional Fisheries Manager in the area where stream crossing construction is to take place. A cooperative review of stream crossing construction plans that results in a matually acceptable approach will significantly reduce damage to our fisheries resource.

Revisions to these procedures can be expected from time to time as more experience is gained.

SUMMARY

1. Stream crossing designers should consider protection of fish habitat and fish passage for all streams that are frequented by fish (Sec. 1.1). Unobstructed fish passage in streams and protection of fish habitat are required by law (Sec. 1.2). Designers should consult the regional fisheries manager for his expertise in achieving these goals (Sec. 2.1, 2.2, 3.1, 4.2).

2. Stream crossing designs which retain the natural stream morphology are preferred (Sec. 3.3).

3. The maximum prolonged swimming speed of spawning migrant fish should not be exceeded by excessive culvert velocities for more than three consecutive days, once during the average annual flood, and 7 days once in 50 years. Extended delay periods also cannot be tolerated for non-spawning migrants (Sec. 4.2).

4. Culverts should be designed for outlet control with little or no backwater effect or ponding, so that no structural damage occurs to the crossing which could result in a large influx of sediments to the stream (Sec. 4.3).

5. The minimum culvert diameter for fish passage should be 0.8 m (Sec. 4.3).

6. Culverts should fit stream alignment and be positioned where no sudden increases in water velocity above or below the crossing exist (Sec. 4.4).

7. Culverts should be located where stream gradient is as close to zero as possible (Sec. 4.4).

8. Culverts inverts should be laid a minimum of 30 cm below grade (Sec. 4.5).

9. Construction should be timed to avoid coincidence with fish spawning runs (Sec. 5.1).

10. Gravel removal or other borrow operations should occur no closer than 100 m from any river channel (Sec. 5.2).

11. Slope clearing wherever possible, should be discontinued at a minimum of 100 m horizontally from the design flood high-water mark (Sec. 5.3).

12. Streambed protection is required upstream 1.5 to 2 times the expected head of the structure and should terminate at least 2 pipe diameters past the culvert outlet. This should tie in with side slope protection extending from the streambed to 0.3 m above the normal high-water mark or to the top of the existing bank, whichever is less (Sec. 5.4).

13. Road drainage from the disturbed area containing excessive sediment loading should not enter a stream through immediate access or from surface run-off (Sec. 5.5).

14. The designer should have a specific plan for instream sediment retention during construction (Sec. 5.6).

15. Frozen earth, muck, muskeg, silt, brush and other debris are unsuitable for reinforcement of temporary crossing, or for slopes and foundations of permanent crossings (Sec. 5.7).

16. Care should be taken to ensure that construction materials or fuel does not enter streams (Sec. 5.7).

17. Stream crossings should be periodically inspected to ensure that no erosion or blockage problems develop (Sec. 6.1).

18. Upon road or railway abandonment stream crossings should be removed, and all disturbed areas should be stabilized to prevent continued erosion (Sec. 7.1).

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PART 1

INTRODUCTION

1.1 Scope

This report is intended to provide civil engineers with practical planning and design procedures, which when followed will reduce or avoid adverse impacts to fish populations when stream crossings are being constructed, maintained or abandoned. It brings together the collective thinking of the Federal and Provincial agencies whose authorized responsibility is rational management of fisheries resources.

The procedures or guidelines apply to any natural stream, regardless of its size, whether perennial or intermittent, that is used by migratory or resident fish during any period of the year. They apply to new crossings to be installed, inadequate crossings to be corrected and old crossings to be repaired or replaced where there is potential for significant adverse impact to fish populations. In all cases, consultation with the regional fisheries manager will enable the civil engineer to determine whether or not fish protection is required in the stream crossing design.

A glossary of biological terms used in this report is presented in Appendix I.

The guidelines are not meant to be directives that apply in all areas and under all conditions. Detailed specifications for crossing design cannot be given since the fish species involved may vary greatly depending on the area concerned. Also, streamflow

data for most of the streams in Manitoba are not available. In most cases stream discharges will have to be estimated from the amount of drainage area upstream of a crossing site. Approximate areas of drainage basins in Manitoba are given by Fedoruk (1970). Design and construction engineers should be free to use alternative solutions to meet fisheries protection objectives. These objectives are:

i. To allow wherever possible free and unobstructed fish passage through stream crossings so that fish may migrate to spawning, rearing, feeding, overwintering, or other critical areas without harmful delay.

ii. To protect stream bottom and banks from accelerated erosion processes to minimize disturbances of critical fish habitat.

iii. To avoid impairment to the physical condition of fish and their habitats which may result from introduction of hazardous construction materials or any deleterious substance into the stream community.

These guidelines apply to the proponents or owners of a stream crossings. It is their responsibility to assure that their agency or firm, its contractors and subcontractors adhere to the intent of these guidelines.

1.2 Legislative Authority

1.2.1 Under the British North America Act of 1867, the Government of Canada has jurisdiction over inland and coastal fisheries. The Fisheries Act defines responsibilities for the management

and protection of fisheries resources. The important sections of the Fisheries Act which pertain to stream crossings are:

Section 20 - Construction of fishways

Section 30 - Destruction of fish

Section 31 - Harmful alteration of fish habitat

Section 33 - Pollution of water

Other sections of the Act which may apply are:

Section 12 - Destruction of fry

Section 24(1) - Obstruction of main channels

Section 25 - Protection of fish in fishways

Section 27 - Obstruction of fish by weirs

Section 28 - Screening of water intakes

1.2.2 In 1930, the Federal Government entered into agreements with the provinces of Manitoba, Saskatchewan and Alberta, whereby much of the jurisdiction over public lands and natural resources was transferred to the Prairie Provinces. By way of these agreements, Provincial authorities are empowered to administer and enforce the Fisheries Act.

1.2.3 In addition to the Fisheries Act, there are other Federal and Provincial statutes which may be relevant to stream crossings. They are:

Federal Statutes

1. Canada Water Act
2. Navigable Water Protection Act
3. Environmental Contaminants Act

Manitoba Statutes

1. Clean Environment Act
2. Act Respecting Rivers and Streams
3. Water Resources Administration Act
4. Act Respecting Provincial Water Powers

PART 2

PLANNING GUIDES

2.1 Route Selection

2.1.1 Planning the route with environmental protection in mind will minimize potential damage to fish stocks and help to reduce unforeseen costs to repair or replace problem crossings in the future. The regional fisheries manager responsible for the area should be consulted at this stage so that environmentally sensitive areas may be identified and avoided in the initial planning process. Close liaison should be maintained from that time onwards. Regional fisheries managers can be contacted through the Director of Fisheries, Manitoba Department of Natural Resources at 1495 St. James Street, Winnipeg, Manitoba, R3H 0W9

2.1.2 Adequate lead time may be necessary in some instances so that fisheries data can be collected and analyzed in order to choose a route that is environmentally acceptable and meets transportation needs.

2.1.3 A route that minimizes the number of streams to be crossed is preferred. Each stream crossing involves potential damage to fish stocks and may increase costs of construction.

2.1.4 A proposed route should not encroach within 100 m (350 ft) of a watercourse except when crossing. This forces the alignment onto higher and drier sites in many cases.

2.2 Site Selection

2.2.1 Designated or known fish spawning, rearing, feeding or overwintering areas should not be considered as suitable crossing sites. If it is unavoidable, the use of a bridge with a high approach rather than a culvert will have to be specified to limit disturbance to the channel. To avoid silt deposition on the spawning area the site should otherwise be selected at least 500 m (1600 ft) downstream from the critical areas with adequate provision for safe passage of fish.

2.2.2 Crossings should be chosen as far upstream from a river mouth or as far downstream from a lake outlet as possible. River mouths and lake outlet areas are favoured habitats for fish spawning and feeding or are locations through which fish movements are heavy. Crossings should not be placed within 500 m (1600 ft) of them. The crossing at braided portions of a stream should be avoided, otherwise extensive flooding, stream siltation, or failure of the crossing may occur.

2.2.3 Where natural barriers to fish passage, such as waterfalls, exist, the crossing should be selected upstream of the barrier where fish passage would not be affected by bridge or culvert installations.

2.2.4 Crossings should not be considered where actively slumping banks are evident or suspected.

PART 3

DESIGN OPTIONS

3.1 Crossing Design

3.1.1 The main criterion in designing a stream crossing must be that while providing a structurally sound overpass, the structure should not obstruct fish passage along the watercourse, or detrimentally alter the habitat for fish.

3.1.2 In situations where the designer has only a limited amount of hydrological and biological information, a large safety factor should be used in the design. Over-design will help minimize environmental problems and reduce risk of crossing washouts.

3.1.3 The following structures are listed in order of preference by most fisheries managers.

1. Bridge
2. Open-bottom arch culverts
3. Open-bottom box culverts
4. Horizontal ellipse
5. Closed-bottom arch culverts
6. Closed-bottom box culverts
7. Round culverts
8. Multiple culverts of small size

9. Culvert fishways

10. Temporary (makeshift) stream crossings.

11. Ford or low water crossings.

3.1.4 Bridge crossings are the preferred structural type for streams supporting fish populations. Bridges permit retention of the natural streambed and seldom cause fish passage problems. However, in some situations, economics and terrain may dictate that a culvert crossing is preferable to a bridge.

3.2 Bridges

3.2.1 Bridge embankments should not constrict the normal or active stream channel by more than 33%. Approach embankments channel flood waters through a bridge constriction. A constriction in excess of 33% of the normal cross-section of the stream could create a velocity barrier to fish.

3.2.2 Bridge piers or footings should not be built in the stream, where possible. Improperly designed piers or footings may collect debris, which when caught against the piers increase their effective size, concentrates flows and increases scour of banks.

3.2.3 Construction of a concrete apron under the bridge is undersirable from an environmental viewpoint. As a stream degrades, a sudden drop in water level may form at the downstream end of the apron, making it impossible for fish to pass upstream.

3.2.4 A bridge should not be replaced with one or more culverts, unless the stream has no potential for containing fish stocks.

3.3 Culverts

3.3.1 Culvert designs which, as much as possible, retain natural morphological features such as stream width, slope and cross-sectional area are preferred for fish protection. The open-bottomed arch type and open-bottom box culvert maintain the natural stream morphology if they do not constrict the natural channel significantly,so they are generally adequate structures for fish passage.

3.3.2 The horizontal ellipse, pipe arch, corrugated circular, and box culvert with a bottom are acceptable, if these designs are countersunk well below streambed elevation and maintain average stream morphological features at the site. Large armour material in the bed and along the edge of the culvert will provide adequate low velocity zones, so fish can make their way upstream.

3.3.3 Corrugated or smooth pipes are generally impractical for fish passage due to their circular geometry. A circular culvert usually reduces channel cross-sectional area, causing high velocities within the culvert and a restriction to the free flow of debris. At low river flows, the flow area within the culvert is low, and high water velocities are retained. These culverts are not recommended where fish passage is required.

3.3.4 A single large culvert rather than several small culverts is preferred. The single culvert is less likely to become blocked. If multiple culverts are used,migrant fish may

not find or use the barrel designed for passage. When two or more culverts are available, fish will generally be attracted to the one with higher velocities. Fish will also attempt to pass through the wider of two or more culverts of equal velocity.

3.3.5 Pools should be provided, as indicated in Whitehead (1978), upstream and downstream of a stream crossing to permit a resting area for migrant fish.

3.3.6 Sufficiently spaced large sized culverts at the same elevation may provide exit and entrance inter-pool areas of slack water for fish to rest. A minimum of 2 m (6 feet) should be established between adjacent culverts circumferences to provide adequate resting area.

3.3.7 Construction of a fishway within a culvert is not recommended unless other options are unsatisfactory. A review of culvert fishway designs is given by Whitehead (1978). Dane (1978), Katopodis (1977) and Katopodis et al. (1978) provide guidelines for their usage.

3.3.8 Temporary (makeshift) stream crossing designs should adhere to the same environmental constraints as permanent crossings. Makeshift ford crossings should be restricted to streams which do not support significant populations or migrations of fish. During critical periods, temporary crossings should not be placed in streams used by migratory fish. Where temporary winter crossings are necessary,

these should be constructed of ice and snow only. If reinforcement materials are required, delimbed logs may be used. Brush, dirt or other debris should not be included. Reinforcement materials should be removed before the spring freshet.

PART 4

DESIGN CONSTRAINTS

4.1 Period of Delay

4.1.1 Timing is very important for spawning migrations (Table 1). Extended delay periods may adversely affect spawning fish and subsequent fish production. Consideration should be given to proximity of spawning grounds. The need to assure unimpeded fish movements upstream becomes more important as spawners approach their usual spawning areas. Blockages or delays will result in fish spawning in suboptimal areas. For culvert designs to satisfy these criteria, a three-day impassable period should not be exceeded during the average annual flood, defined as having a 2.33 year recurring interval. A seven-day delay in fish movement through the crossing should not be exceeded more than once in the design period of 50 years. There should be no delay if the spawning grounds are located immediately upstream of a stream crossing.

4.1.2 Although delays do not subject non-spawning migrant fish to the same stresses as spawners, prolonged delay periods

can not be tolerated by non-spawning migrants. Delays subject fish to physical damage, and make fish more vulnerable to disease, predation and capture.

4.2 Current Velocity in the Culverts

4.2.1 To allow fish passage, culverts must be designed so that flow velocities are below the maximum prolonged swimming capability of fish. Since swimming capability depends on the species of fish, culvert design will be determined by the major species utilizing the stream. (Listings of large fish species which are likely to occur in various Manitoba watersheds are presented in Appendix II). Swimming capability also depends on the size and state of maturity of fish, transit time and distance, water temperature and dissolved oxygen level. The swimming capabilities of some Manitoba fishes given various conditions as well as a means of determining acceptable water velocities for several fish species in culverts of various lengths are presented in Appendix III. Regional fisheries managers will have or can obtain information on fish populations in streams and can evaluate fish swimming capabilities to determine the maximum allowable culvert velocity for fish passage. The stream crossing designer is responsible for consulting with the regional fisheries manager to meet this objective.

4.2.2 The maximum drawdown through the culvert should be minimized. An abrupt increase in water velocities caused by a drawdown of water at the entrance or exit may form a localized velocity barrier to fish migration.

4.3 Culvert Capacity

4.3.1 Culverts should have sufficient capacity to pass a flood having a frequency of occurrence, on the average, of once in 50 years. There should be a freeboard allowance for passing of debris.

4.3.2 Culverts should be designed for outlet control rather than inlet control in consideration of fish passage requirements.

4.3.3 The minimum culvert diameter for fish passage should be 0.8 m (30 inches).

4.4 Culvert Position

4.4.1 Culverts should be positioned where there are no sudden increases in water velocity above, below or at the crossing location and where channel gradient is as near zero as possible.

4.4.2 Culverts should fit the stream channel alignment and should not be positioned on a sharp bend in the stream channel so that discharge is directed at a potentially unstable riverbank.

4.4.3 Where possible, the crossing should be aligned perpendicular to the direction of flow to minimize construction area, culvert lengths and downstream bank erosion. Fish passage is generally easier through shorter culverts.

4.4.4 Stream cutoffs or diversions should be avoided or minimized. Bypassing the meander loop increases the stream gradient causing higher velocities, increased potential for erosion and deterioration of aquatic habitat.

4.5 Gradient and Installation

4.5.1 Culvert gradient should be kept as close to zero as foundation and stream conditions permit. The maximum culvert slope that may be installed when employing baffles is 5 percent (Katopodis et al. 1978)

4.5.2 Culvert inverts should be laid a minimum of 30 cm (12 inches) below normal streambed elevation to allow for natural rock and rubble to be recruited. Recommended depths to countersink arch pipe culverts are given in Table 2. Major blockages to fish migration occur when culvert inlets are installed above the normal streambed elevation or if scour lowers the streambed downstream of the culvert outlet. The resulting vertical drop forces fish to jump in order to enter the culvert. Jumping ability can be exceeded, thus blocking the migration.

4.5.3 Culverts should never be installed on wet muck, muskeg, sod, frozen earth, permafrost or large rocks. Soft, unsuitable foundation material should be excavated below gradeline and backfilled with suitable granular material such as pit-run or crushed rock. Special care should be taken during the backfilling operations to ensure that hydrostatic uplifting or side movements of the culvert

does not occur. Partial or total failure of a culvert could lead to total blockage of fish movements.

PART 5

CONSTRUCTION GUIDES

5.1 Scheduling

5.1.1 Construction activity should be limited to the times of year when fish movement through a reach is minimal. Critical fish spawning migration periods are given in Table 1. Blockages or stream disturbances resulting from instream construction cannot be tolerated during these periods. Construction in winter or during low flows in summer causes the least disturbances to fish stocks.

5.2 Gravel Removal

5.2.1 Gravel removal operations should be limited to areas above the design flood high water stage and no closer than 100 m (350 ft) from any active river channel to prevent introduction of sediment.

5.2.2 No excavations should encroach within stream boundaries or result in slope failure. Sediment laden runoff from the pit must not enter streams. As a precaution, settling basins should be installed.

5.2.3 Material should not be removed from active flood plains, unless fisheries managers are satisfied that the stream does not support or have potential to support fish

populations. Such an operation should be conducted only after full onsite consultation with the regional fisheries managers.

5.3 Cuts and Clearing

5.3.1 Side-hill cuts and slope clearing can initiate shallow slope failures, expose soil to erosion and gullying, and result in stream siltation. To ensure stability, attempts should be made to restrict the right-of-way clearing only up to 100 m (350 ft) horizontally from the design flood high water mark. For slopes that exceed 1 in 3, clearing should be stopped at the top of the slope. Where it is deemed necessary to clear closer to the stream, special precautions should be taken to ensure erosion and sediment influx to the stream is controlled.

5.4 Erosion Control

5.4.1 All disturbed areas should be stabilized after culvert installation. The streambed should be armoured with heavy rip rap material to prevent bed scour. The armour should extend upstream 1.5 to 2 times the expected head of the structure and terminate at least 2 pipe diameters past the culvert outlet. A suggested method of treatment involves placing a 0.6 m (2 ft) thick rip rap blanket on top of a 0.3 m (1 ft) thick graded gravel blanket. Rip rap armour should be of suitable size to withstand high water velocities (Table 3).

5.4.2 Side slope protection is required upstream and downstream of the culvert, and should be tied in with the armoured streambed blanket. Slopes should be stabilized in a manner appropriate for the soils, vegetation, grade and ice content encountered, and be protected with rip rap and vegetal cover as required. Protective rip rap should be placed from the bottom of the streambed to 0.3 m (1 ft) above normal high water, or to the top of the existing bank, whichever is less.

5.5 Drainage

5.5.1 Road drainage from the disturbed area containing excessive sediment loading should not enter the stream through access or surface runoff.

5.5.2 Dispersal of drainage water over undisturbed natural terrain downslope from the roadway is preferred because of the high resistance of such terrain to erosion and its effective removal of any silt load from drainage water.

5.5.3 Until permanent vegetation is established, erosion around the crossing site should be minimized by placing a series of check dams or other energy dissipators within the roadway ditches.

5.6 Instream Silt Retention

5.6.1 During construction, the designer should have a specific plan for erosion control and water diversion around the

work area in the streambed. Temporary weirs or cofferdams may be constructed as required to form settling basins for siltation control. Settling basins should be maintained and cleaned regularly of silt, sand and debris. Upon completion of work, all temporary structures should be removed and the area stabilized.

5.7 Construction Materials

5.7.1 Extreme care should be taken to ensure that no construction materials (eg. cement, lime, concrete) are allowed to enter the waterway. Any potential toxicants to fish should never be pumped, diverted or washed into the stream.

5.7.2 To prevent fuel contamination, fuel storage areas should be located at least 100 m away from the highwater line and be dyked.

5.7.3 All debris from clearing or construction operations should be removed from the stream and adjacent stream area, and be disposed of through burning, chipping or other agreed upon methods, or placed in such a manner that it cannot enter the stream. High ice content waste should be removed, or compacted and covered with some form of insulating material well away from the waterbody.

PART 6

MAINTENANCE GUIDES

6.1.1 Periodic inspection of crossings should be conducted

prior to and during spring break-up. Debris caught on piers and at the entrance to culverts should be promptly removed to prevent an impasse to fish, upstream flooding and to reduce stress on the crossing structure.

6.1.2 After the first heavy rain, stream crossing beds and banks should be checked to see that no erosion or sedimentation problems are developing.

PART 7

ABANDONMENT GUIDES

7.1.1 Upon abandonment of the road or railway, stream crossings should be removed. Construction material, vegetation, overburden or other material used at the crossing site should be disposed of in an approved manner or reused in restoration of stream banks.

7.1.2 All disturbed areas should be stabilized. Such practices should be determined by the needs of each specific site. Stabilization practices should include, but not be limited to, seeding, planting, mulching, and the placement of rock rip rap, or matting.

7.1.3 Seeding and planting operations required for revegetation should be initiated as soon as practicable after removal operations in the area have been completed. If necessary, seeding, planting, and fertilizing should be repeated until revegetation is successful.

PART 8

CONCLUDING REMARKS

All of the foregoing recommendations will do little to protect the fisheries resources unless they are honoured on each project. One poorly installed culvert can affect the fish stocks of an entire drainage basin. Poor culvert design and location is one of the most devastating constraints to fish reproduction (Sopuck and Wright, 1978).

Written specifications in the contract plus consultation with Manitoba regional fisheries managers will help to guarantee that the desired objectives of fish protection are met. When specifically requested, all pertinent plans for stream crossings should be submitted to either the Manitoba Department of Natural Resources or the Canada Department of Fisheries and Oceans for review and comments.

These guidelines have been based on an extensive review (Whitehead, 1978)[1] of currently available literature pertaining to the environmental aspects of stream crossing and road construction. These guidelines may be amended subject to new information and further experience with fish passage through culverts.

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[1] Copies of this report may be obtained through the Director of Fisheries, Manitoba Department of Natural Resources, Winnipeg.

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Table 1. Critical periods for spawning runs (and incubation[1] and hatching) of some fish found in Manitoba streams.

SPECIES	CRITICAL PERIOD
Northern Pike	April to June
Walleye	April to June
Sauger	April to June
Arctic Grayling	April to June
Lake Sturgeon	May and June
Brook Trout	Aug. - Oct. (Oct. to May)
Arctic Char	Aug. - Oct. (Oct. to May)
Lake Whitefish	Sept. and Oct. (Oct. to May)
Cisco	Sept. and Oct. (Oct. to May)

[1]Although the above dates are generally accurate, it is preferable that streams be individually considered.

Table 2. Recommended depths to countersink arch pipe culverts. Source: AASHTO (1975).

Span (ft - in)	Rise (ft - in)	Countersink (in)
6 - 1	4 - 7	21.0
6 - 4	4 - 9	20.5
6 - 9	4 -11	22.0
7 - 0	5 - 1	21.4
7 - 3	5 - 3	20.8
7 - 8	5 - 5	27.4
7 -11	5 - 7	21.7
8 - 2	5 - 9	20.9
8 - 7	5 -11	22.7
8 -10	6 - 1	21.9
9 - 4	6 - 3	23.8
9 - 6	6 - 5	22.9
9 - 9	6 - 7	21.9
10 - 3	6 - 9	24.0
10 - 8	6 -11	26.1
10 -11	7 - 1	25.1
11 - 5	7 - 3	27.4
11 - 7	7 - 5	26.3
11 -10	7 - 7	25.2
12 - 4	7 - 9	27.5
12 - 6	7 -11	26.4
12 - 8	8 - 1	25.2
12 -10	8 - 4	24.0
13 - 5	8 - 5	26.4
13 -11	8 - 7	28.9
14 - 1	8 - 9	27.6
14 - 3	8 -11	26.3
14 -10	9 - 1	28.9
15 - 4	9 - 3	31.6
15 - 6	9 - 5	30.2
15 - 8	9 - 7	28.8
15 -10	9 -10	27.5
16 - 5	9 -11	30.1
16 - 7	10 -11	28.7

Table 3. Size of streambed materials that various velocities of water can transport. Source: White and Bayaillan (1969) as cited by Evans (1972).

Material	Diameter		Mean Velocity	
	(inches)	(mm)	(ft/sec)	(cm/sec)
Silt	0.00002	0.005	0.40	15
Fine sand . .	0.002	0.05	0.66	20
Medium sand .	0.01	0.25	0.98	30
Coarse sand .	0.04	1.0	1.80	55
Fine gravel .	0.1	2.5	2.13	65
Medium gravel.	0.2	5.0	2.62	80
Coarse gravel.	0.4	10.0	3.28	100
Fine pebbles .	0.6	15.0	3.94	120
Medium pebbles	1.0	25.0	4.59	140
Coarse pebbles	1.6	40.0	5.91	180
Large pebbles.	3.0	75.0	7.87	240
Large pebbles.	4.0	100.0	8.86	270
Large pebbles.	6.0	150.0	10.83	330
Boulders . . .	7.8	200.0	12.80	390

PART 10
APPENDICES

APPENDIX I

GLOSSARY

BURST SWIMMING SPEED: Very high speed maintained for less than 15 seconds. Energy for this activity is made available largely from anaerobic processes; consequently the fish fatigues rapidly and may be in a weakened condition afterwards.

CRITICAL SWIMMING SPEED: An operational term used to compare the swimming speeds of different fish. It is measured by subjecting fish to stepwise increases in swimming speed until the fish fatigues. The maximum speed achieved before fatigue occurs is the critical swimming speed.

FISHWAY: A structure that produces pockets of low velocity throughout a given distance to enable fish movement past obstacles.

HABITAT: A typical kind of environment that fish of a specific kind are found in. Habitats include spawning ground and nursery, rearing, feeding and migration areas upon which fish depend, either directly or indirectly, to complete their life cycle.

NON-SPAWNING MIGRANT FISH: A fish that migrates by the necessity to achieve some change of habitat, for example, to search for food, to overwinter or to reduce population pressure from within.

PROLONGED SWIMMING SPEED: The intermediate level of swimming performance which fish can maintain for periods of 15 sec to 20 min. The level of swimming performance varies with species and size of fish, and decreases proportionately with the logarithm of time.

RESIDENT FISH: A young or adult fish which remains in a specific river, stream or lake year-round.

SPAWNING GROUNDS: A specific site in a waterbody that is inherently utilized by a particular fish species for reproduction.

SPAWNING RUN: The migration of fish stocks over a short or extended time to the spawning grounds. The duration of the run depends on the readiness of individuals to spawn.

SUSTAINED SWIMMING SPEED: A wide range of swimming activities that can be maintained for an indefinite period, i.e. longer than 200 min. Activities involved in this type of swimming include position holding, schooling, foraging and migration.

APPENDIX II

Lists of various large fish species occurring in Manitoba watersheds. Drainage basin codes are those used by Water Survey of Canada

ABBREVIATIONS OF FISH NAMES

LS- lake sturgeon

AC- Arctic char

BT- brook trout

LT- lake trout

T - tullibee (lake herring or cisco)

LW- lake whitefish

RW- round whitefish

AG- Arctic grayling

GE- goldeye

ME- mooneye

NP- northern pike

M - muskellunge

C - carp

NS- northern (or longnose) sucker

WS- white sucker

CF- (channel) catfish

B - burbot

WB- white bass

RB- rock bass

SMB- smallmouth bass

LMB- largemouth bass

BC- black crappie

YP- yellow perch

S - sauger

W - walleye

FWD- freshwater drum

HAYES AND GODS RIVER BASIN

4AA- LW, NS, WS, NP, W

4AB- BT, LW, C, NS, WS, NP, W

4AC- LT, LW, NS, WS, NP, W

4AD- BT, LW, NS, WS, NP, W

4AE- LW, NS, WS, NP, W

4AF- LT, LW, NS, WS, NP, W

KASKATTAMA RIVER BASIN

4BC- BT, AG, NS, NP

4BD- BT, AG, NS, NP

SEVERN RIVER BASIN

4CA- LT, LW, NS, WS, NP, W

4CD- NS, WS, NP, W

NELSON RIVER BASIN

Qu'Appelle River

5JM- WS, NP, CF, W, S, RB, YP

Saskatchewan River

5KG- LS, GE, NS, WS, NP, W, S, YP

5KH- LS, GE, NS, WS, NP, W, S, YP

5KF TO 5KL- LS, GE, NS, WS, NP, W, S,YP

Dauphin River

5LC- NS, WS, NP, W, S, YP

5LD- NS, WS, NP, W, S, YP

5LE- NS, WS, NP, W, S, YP

5LF- LW, NS, WS, NP, W, S, YP

5LG- NS, WS, NP, W, S, YP

5LH- NS, WS, NP, W, S, YP

5LJ- NS, WS, NP, W, S, YP

5LK- LW, NS, WS, NP, W, S, YP

5LL- NS, WS, NP, C, W, S, YP

5LM- LW, NS, WS, NP, W, S, YP

5LN- NS, WS, NP, C, W, S, YP

Assiniboine River

5MD- WS, NP, W, S

5ME- WS, NP, W, S, RB

5MF- WS, NP, W, S, YP

5MG- GE, ME, NP, WS, RB, YP, W, S

5MH- GE, ME, NP, WS, RB, YP, W, S

5MJ- GE, ME, NP, WS, C, CF, RB, YP, W, S, FWD

Souris River

5NF- WS, NP, W

5NG- WS, NP, W

Pembina River

5OA- NP, WS

5OB- NP, WS

Red River

5OC- GE, NP, C, WS, CF, B, BC, YP, W, S, FWD

5OD- GE, NP, C, WS, CF, B, RB, YP, W, S, FWD

5OE- NP, GE, C, WS, CF, B, YP, W, S, FWD

5OF- GE, NP, C, WS, CF, B, YP, W, S, FWD

5OG- GE, NP, C, WS, CF, B, YP, W, S, FWD

5OH- NP, C, WS, CF, YP, W, S

5OJ- LS, LW, GE, NP, C, WS, CF, WB, YP, W, S, FWD, B

Winnipeg River

5PD- LS, LW, NP, M, NS, WS, B, LT, SMB, LMB, W, S, YP

5PG- LW, LT, ME, GE, NP, NS, M, SMB, LMB, YP, W, S, LS

5PF- LS, LW, T, GE, NP, NS, WS, CF, B, W, S, YP, ME

5PH- ME, GE, NP, WS, YP, W, S

5PJ- ME, GE, NP, WS, B, W, S

Lake Winnipeg

5RA TO 5SH- T, LW, LS, NP, C, NS, WS, CF, B, WB, RB, YP, W, S, FWD

Grass River

5TA- T, LW, NP, NS, WS, B, W

5TB- T, LW, NP, NS, WS, B, W

5TC- LS, T, LW, NP, NS, WS, B, W

5TD- LS, T, LW, NP, NS, WS, B, W

Burntwood River

5TE- LS, T, LW, NP, NS, WS, B, W

5TF- LS, T, LW, NP, NS, WS, B, W

5TG- T, LW, NP, NS, WS, B, W

Nelson River

5UA TO 5UE- LS, T, LW, NP, C, NS, WS, B, W, S

5UF TO 5UH- LS, BT, T, LW, NP, C, NS, WS, B, W

CHURCHILL RIVER BASIN

Cochrane River

6DA- AG, T, LW, NP, NS, WS, B, W

6DB- LT, T, LW, AG, NP, NS, WS, W, B

Churchill River

6EA TO 6EC- LS, T, LW, NP, NS, WS, B, W, S, YP

6FA - LS, LT, T, LW, NP, NS, WS, B, W, S

6FB - LS, T, LW, NP, NS, WS, B, W, S

6FC - LS, LT, T, LW, NP, NS, WS, B, W, S

6FD - LS, BT, T, LW, AG, NP, NS, WS, B, W, S

OWL RIVER BASIN

6FE- BT, AC, LW, AG, NP, NS, B

SEAL RIVER BASIN

Seal River

6GA- LT, LW, AG, NP, NS, B, W

6GB- LT, LW, AG, NP, NS, B, W

6GD- AC, BT, LT, LW, RW, AG, NP, NS,B, W

Knife River

6GC- AC, BT, LT, LW, AG, NP, NS, B, W

CARIBOU RIVER BASIN

6GE- AC, BT, LT, LW, AG, NP, NS

THLEWIAZA RIVER BASIN

6HA- LT, LW, RW, AG, NP, NS

6HC- AC, LT, LW, RW, AG, NP, NS

KAZAN RIVER BASIN

6LA- LT, LW, RW, AG, NP, NS

APPENDIX III

Tables of swimming speeds of various species of fish (extracted from Beamish, 1978) and the method used by Jones *et al.* (1974) for estimating the critical velocity of some fish species in culverts of various lengths.

Table A: Prolonged swimming speeds determined for species of freshwater fishes found in Manitoba waters.

Species	Number	Total Length (cm)	Weight (g)	Vel. increments (cm/sec)	Time between increments (min)	Swimming time at max. vel. (min)	Maximum velocity cm/sec	Maximum velocity l/sec	Exper. temp. (C)	Reference
Rainbow trout	129	-	23-196	12-27	60	60	19-73	-	5-15	Rao (1968)
" "	10	20.2	-	-	-	-	30-70	1.5-3.5	15	Kutty (1968)
" "	128	7.5-24	5-100	11-18	1	1	48-70	5.5-6.4	10	Fry & Cox (1970)
" "	150	5.7-6.0	1.4-1.7	2.3-3.0	10-20	10	25.1-43.3	-	-	Butler & Milleman(1971)
"	150	5.7-6.0	1.4-1.7	2.3-3.0	10-20	10	13.7-34.3	-	-	Butler & Milleman(1971)
Brook Trout	6	9.9	-	3	30	30	34.7	3.50	15	Peterson (1974)*
" "	6	9.6	-	3	30	30	37.4	3.90	15	Peterson (1974)*
" "	6	10.2	-	3	30	30	47.6	4.67	15	Peterson (1974)*
" "	18	10.3	-	3	30	30	49.5	4.82	15	Peterson (1974)
" "	6	10.4	-	3	60	60	48.2	4.60	15	Peterson (1974)
" "	28	10.1	-	3	30	30	48.9	4.80	15	Peterson (1974)
" "	6	10.9	-	3	15	15	55.9	5.10	15	Peterson (1974)
" "	6	11.0	-	3	1.5	15	67.9	6.20	15	Peterson (1974)
" "	6	11.6	-	3	0.5	15	88.7	7.70	15	Peterson (1974)
Lake Trout	-	-	27.7	4-12	2	2	35-54	-	8-23	Gibson & Fry (1954)
" "	-	-	82.8	4-12	2	2	48-83	-	10-22	Gibson & Fry (1954)
Northern pike	-	16.5	-	-	-	2	210	12.7	-	Gray (1953)
" "	-	37.8	-	-	17	-	148	3.9	-	Magnan (1929)
Carp	-	13.5	-	-	-	-	170	12.6	-	Gray (1953)
Largemouth bass+	-	21.3	-	-	-	-	88.0	4.1	-	Magnan (1929)
" "	30	5.7	-	Gradually until laps lost		3	18.8-30.7	3.3-5.4	20	MacLeod (1967)
" "	105	8.0-8.5	4.8-6.4	2.3	10	10	20-41	2.4-5.0	25	Dahlbert et al. (1968)
" "	65	8.0-8.6	5.6-7.4	2.3	10	10	24-43	2.8-7.8	25	Dahlbert et al. (1968)
" "	45	2.0-2.2	-	2.2	3	3	4.8-14.6	2.2-6.5	5-20	Larimore & Duever (1968)
" "	53	2.0-2.2	-	2.2	3	3	5.2-16.8	2.3-7.8	5-25	Larimore & Duever (1968)
" "	51	2.0-2.2	-	2.2	3	3	7.2-23.9	3.3-10.1	10-30	Larimore & Duever (1968)
" "	51	2.0-2.2	-	2.2	3	3	11.1-27.0	5.1-12.4	10-30	Larimore & Duever (1968)
"	45	2.0-2.2	-	2.2	3	3	8.5-29.2	3.6-13.0	10-30	Larimore & Duever (1968)
" "	30	2.0-2.2	-	2.2	3	3	17.7-31.2	7.8-13.6	20-30	Larimore & Duever (1968)
" "	30	5.7	-	Gradually until laps lost		3	18.8-30.7	3.3-5.4	20	Beamish (1970)
" "	32	15-27	45-270	10	30	30	24.0-55.0	1.6-2.0	10	Beamish (1970)
" "	45	15-27	45-270	10	30	30	33.0-58.0	2.2	15	Beamish (1970)
" "	45	15-27	45-270	10	30	30	45.0-63.0	2.3-3.0	20	Beamish (1970)
" "	48	15-27	45-270	10	30	30	47.0-64.0	2.4-3.1	25	Beamish (1970)
" "	51	15-27	45-270	10	30	30	48.0-66.0	2.4-3.2	30	Beamish (1970)
" "	38	15-27	45-270	10	30	30	49.0-60.0	2.2-2.7	34	Beamish (1970)
Yellow perch	137	0.6-1.4	-	Gradually to prescribed vel.		60	0.6-4.6	1.0-3.3	13	Houde (1969)
Walleye	181	0.7-1.5	-	Gradually to prescribed vel.		60	0.5-5.0	0.7-3.3	13	Houde (1969)

* Subjected to concentration of fenitrothion.

\+ Largemouth bass is not a common species in Manitoba. Data are presented since swimming capabilities of largemouth bass may be similar to smallmouth bass which is found in SE Manitoba.

Table B:Sustained cruising speeds determined for species of freshwater fishes found in Manitoba waters.

Species	Length (cm)	Number	Swimming Speed						Reference
			Range		Mean		Maximum		
			cm/sec	l/sec	cm/sec	l/sec	cm/sec	l/sec	
Sturgeon sp.	ca. 110	6	130-500	1.2-4.5	165	1.5	-	-	Malinin et al.(1971)
Sturgeon sp.	ca. 110	-	-	-	15	0.14	-	-	Malinin et al.(1971)
Sturgeon sp.	ca.110	-	25-58	0.2-0.5	33	0.3	-	-	Malinin et al.(1971)
Rainbow trout	72	2	9-44	0.1-0.6	-	-	-	-	Johnson (1960)
Northern pike	ca. 80	-	-	-	5.5	0.07	300	3.8	Poddubny et al.(1970
Burbot	ca. 50	-	-	16.7	0.3	-	-	-	Malinin (1971)
White bass	26-38	26	5-21	0.2-0.7	13.0	0.4	-	-	Hasler et al.(1969)

Table C: Burst swimming speeds determined for species of freshwater fishes found in Manitoba waters.

Species	Number	Length (cm)	Velocity cm/sec	Velocity l/sec	References
Rainbow trout	-	-	550-1050	-	Lane (1941)
" "	10	58-67	186- 226	2.8-3.7	Paulik & DeLacy (1957)
" "	6	61-81	536- 817	7.5-13.4	Weaver (1963)
Brook trout	1	11.2	93	8.3	Peterson (1974)
Pike sp.	-	-	590-1370	-	Lane (1941)
Northern pike	1	-	360-450	-	Stringham (1924)
Carp	-	35.0	236	8.2	Komarov (1971)
"	3	-	-	5.2	Regnard (1893)
Yellow perch	-	11.5	145	12.6	Komarov (1971)

TABLE D : Critical swimming speeds determined for species of freshwater fishes found in Manitoba waters.

Species	Number	Length (cm)	Weight (g)	Vel. Increments cm/sec	Time Between Increments (min)	Critical Velocity cm/sec	Critical Velocity l/sec	Exper. Temp. (°C)	Reference
Goldeye	2	22.5	--	10	10	60	2.7	12	Jones et al. (1974)
Lake whitefish	159	6-51	2-1500	10	10	34.1-72.1	1.4-5.7	7-19	Jones et al. (1974)
Rainbow trout	15	10.9	13.2	9	20	65.9	6.1	11.9	Jones (1971)
" "	18	12.5	23.4	9	20	43.4	3.5	14.1	Jones (1971)
" "	73	29.2	26.4	6	60	58.1	2.0	15.0	Webb (1971)
" "	15	11.8	18.1	9	20	52.3	4.4	22.4	Jones (1971)
" "	6	30.6	--	10	10	66.6	2.2	--	Jones et al. (1974)
" "	6	32.8	--	10	10	91.0	2.8	--	Jones et al. (1974)
Arctic char	11	35.5	--	10	10	100.2	2.8	12.0	Jones et al. (1974)
Arctic grayling	94	7-34	1.5- 800	10	10	52-72	1.9-7.5	12.0-19.0	Jones et al. (1974)
Northern pike	192	12-62	7-1800	10	10	19-47	0.8-1.6	12.0	Jones et al. (1974)
Northern sucker	169	4-53	0.5-2200	10	10	23-91	1.7-5.8	7-19	Jones et al. (1974)
White sucker	20	17-37	50-550	10	10	48-73	2.0-2.8	12-19	Jones et al. (1974)
Channel catfish	25	14.0-15.4	--	6	20	31.7-61.4	2.1-4.2	15-35	Hocutt (1973)
Burbot	56	12-62	7-1800	10	10	36-41	0.7-3.0	7-12	Jones et al. (1974)
Largemouth bass	15	5.2- 6.4	--	6	20	30.6-50.0	5.2-8.1	15-35	Hocutt (1973)
" "	10	10.2	--	10	10	45.7	4.5	25	Farlinger & Beamish (1977)
" "	10	10.0	--	10	60	35.1	3.5	25	Farlinger & Beamish (1977)
Yellow perch	20	9.5	--	5	15	1.55-2.10	1.6-2.2	10	Otto & Rice (1974)
" "	20	9.5	--	5	15	25.2-33.0	2.7-3.5	20	Otto & Rice (1974)
" "	30	9.5	--	5	15	33.5	3.5	20	Otto & Rice (1974)
" "	30	9.5	--	5	15	15.5	1.6	10	Otto & Rice (1974)
Walleye	54	8-38	4-500	10	10	38-54	2.2-4.7	19	Jones et al. (1974)

Method For Determining Critical Velocities For Fish Passage Through Culverts (from Jones et al. 1974).

Critical velocity data for 8 species of Manitoba fish can be obtained by solving the regression equation -

$$V = KL^e$$

where: V = critical velocity in cm/s

L = fork length in cm

K = constant

e = exponent

K and e values for eight Manitoba fish species are given in Table E for culverts of 100 m in length.

On the basis of a 10 - minute transit time, curves can be determined to illustrate the smallest size of fish that can be expected to move upstream through a 100 m culvert at various water velocities. These curves can be derived as follows: to achieve 100 m of headway in 10 minutes requires a ground speed of 17 cm/s (swimming speed - water speed).

Critical velocity - water velocity = 17 cm/s

but

Critical velocity = KL^e

so

$$KL^e = \text{water velocity} + 17$$

$$L^e = \frac{\text{water velocity} + 17}{K}$$

$$L = e\sqrt{\frac{\text{water velocity} + 17}{K}}$$

From any point on a curve, a fish of the size indicated, would be fatigued after 10 minutes and would not be able to make any sustained efforts for some time. The associated water velocities therefore represent the maximum permissible for culverts of 100 m in length, in order for fish of the size specified to pass through. For shorter culverts, the curves would be the same but moved to the right. For example, for a 50 m culvert, the ground speed need only be about 8 cm/s and the curves would be shifted to the right by 9 cm/s (17 - 8). Note that this relationship will pertain until culvert lengths are such that burst speed becomes significant.

Table E. Relationship between fork length, weight and critical velocity for 8 species of Manitoba fish (from Jones et al. 1974).

Species	n	Length range (cm)	Weight range (g)	Condition factor[a]	Weight/length correlation coefficient	Length-velocity regression ($V = KL^e$) K	e	Length-velocity correlation coefficient	p-value for correlation coefficient
Northern pike	192	12-62	7-1800	0.66 ± 0.01	0.96	4.9	0.55	0.441	0.001
Walleye	54	8-38	4- 500	0.98 ± 0.02	0.94	13.07	0.51	0.004	0.1
Arctic grayling	94	7-37	1.5- 800	1.03 ± 0.02	0.97	36.23	0.19	0.221	0.02
	11	21-34	90- 500	1.02 ± 0.03	-	91.64	-0.14	-0.104	0.1
Flathead chub	28	17-30	40- 300	0.90 ± 0.02	0.98	6.42	0.67	0.308	0.1
Longnose sucker	169	4-53	0.5-2200	1.03 ± 0.01	0.96	11.03	0.53	0.787	0.0001
White sucker	20	17-37	50- 550	1.37 ± 0.21	0.90	10.03	0.55	0.501	0.02
Burbot	56	12-62	7-1100	0.51 ± 0.01	0.96	30.6	0.07	0.045	0.1
Lake whitefish	159	6-51	2-1500	1.09 ± 0.02	0.94	18.2	0.35	0.36	0.0001

[a] Condition factor = $\frac{100W}{L^3}$ where W = weight (g), L = length (cm).